

Characterization of Mesoscale Predictability

Dale R. Durran
University of Washington
Department of Atmospheric Sciences
Box 351640
Seattle, WA 98195-1640
phone: (206) 543-7440 fax: (206) 543-0308 email: durrand@atmos.washington.edu

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<http://www.atmos.washington.edu/~durrand/>

LONG-TERM GOALS

One of the major efforts in the atmospheric sciences has been to develop and implement high-resolution forecast models and to improve their parameterization of unresolved physical processes (boundary-layer transport, cloud microphysics...). For the last three decades, the relatively pessimistic predictions of Lorenz (1969) about the predictability of small-scale (i.e., mesoscale) atmospheric features have been largely ignored as routine weather forecasts were conducted at increasingly fine scale. Recent research suggests there are nevertheless, significant limitations to the predictability of mesoscale atmospheric circulations. Our goal is to develop an understanding of the predictability of such circulations in forecasts generated by state-of-the-art high-resolution mesoscale models.

OBJECTIVES

Specific questions addressed in our research include:

1. How commonly does rapid growth of initial errors occur in mesoscale meteorological settings?
2. How sensitive are these results to different strategies for developing the initial ensemble spread using the ensemble Kalman filter?
3. How can ensemble forecasts be best used to identify and help predict these difficult events?

The answers to these questions are of direct benefit to Navy forecasters using COAMPS to produce aviation and other forecasts of mesoscale phenomena.

APPROACH

The P.I. and graduate student Matt Gingrich, together with Drs. James Doyle and P. Alex Reinecke of NRL, are using the COAMPS model to conduct 100-member ensemble simulations of high impact events. Under previous support we considered downslope windstorms (Reinecke and Durran, 2009), which, it had been argued, had high mesoscale predictability. More recently, we have considered the prediction of lowland snow in the Puget Sound lowlands. Both of these weather phenomenon have exhibited high sensitivity to initial conditions in the sense that the spread within a large initial

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ensemble (either 70 or 100 members) grew vary rapidly over time scales much shorter than anticipated. Part of the motivation for this effort is to help inform the community of the need to move beyond deterministic mesoscale forecasts, which despite all the talk about ensemble prediction, are still the backbone of military, civilian and private meteorological forecast.

WORK COMPLETED

Our paper “Large-Scale Errors and Mesoscale Predictability in Pacific Northwest Snowstorms” (written in collaboration with James Doyle and Alex Reinecke), has been conditionally accepted for publication in the *Journal of the Atmospheric Sciences*, and a revised version is currently under review. The results in this paper will be discussed in the following section. In addition graduate student Mark Gingrich has investigated the ensemble calibration of the COMAPS forecasts and also of ensembles of simulations based on two idealized chaos models created by Lorenz. Finally, Mark has also identified two more snow events for which we are just beginning to conduct full ensemble simulations. Both of these cases are East-Coast snowstorms: an event during February 5-7, 2010 that was well forecast by the operational models (including the synoptic-scale ensemble guidance) and a second event on December 24-26, 2010 that was poorly forecast by both the operational models and the ensemble guidance. In addition to allowing us to compare two cases with apparently different rates of ensemble spread, both cases involve vigorous convection over the southeastern US, which has the potential to exert more upscale influence than the weak convection associated with the Puget Sound snow events.

RESULTS

The predictability of lowland snow in the Puget Sound region of the Pacific Northwest was explored by analyzing the spread in 100-member ensemble simulations for two events from December 2008. Sensitivities to the microphysical and boundary-layer parameterizations in these simulations were minimized by estimating the likely precipitation type from the forecast 850-hPa temperatures and the established rain-snow climatology. Our results suggest the ensemble spread in events such as these, which were triggered by amplifying short waves, may grow to include significant numbers of *both* rain-likely members and snow-likely members at forecast lead times as short as 36 hours.

An example of the ensemble spread that can develop in 36-hour forecasts is shown in Fig. 1, which compares the 850-hPa temperatures and mean sea-level pressure (MSLP) averaged over the 17 coldest and 17 warmest ensemble members for a forecast valid at 1200 UTC on 18 December 2008. The sorting metric for the full 100-member ensemble is the 850-hPa temperatures averaged over the metric box shown in red in each panel of Fig. 1. The cold (warm) subset consists of those 17 members with the coldest (warmest) metric box temperatures at forecast hour 36. As apparent in Fig. 1, dramatic differences in the temperature field and in the position of the low-pressure center have developed between the cold- and warm-subset means. The difference in average 850-hPa metric box temperatures between the warm-and cold-subset means is 9°C, far higher than the 4°C range that discriminates between rain and snow in the SEATAC climatology (Ferber, et al., 1993).

The initial conditions giving rise to the 36-hour differences are plotted for the warm- and cold-subset means in Figs. 2a,b. The upper-level potential vorticity (PV) distribution (shown by the shaded contours of θ on the 2 PVU surface), the lower-level thermal field (shown by the white contour lines of 850-hPa temperature), and the surface pressure fields (black contours) for both subset means appear very similar at the initial time---the most apparent differences are insignificant variations in regions of

weak gradients. Thus, the large differences between the warm- and cold-subset means shown in Fig. 1 cannot be easily anticipated from the much smaller differences in their initial states.

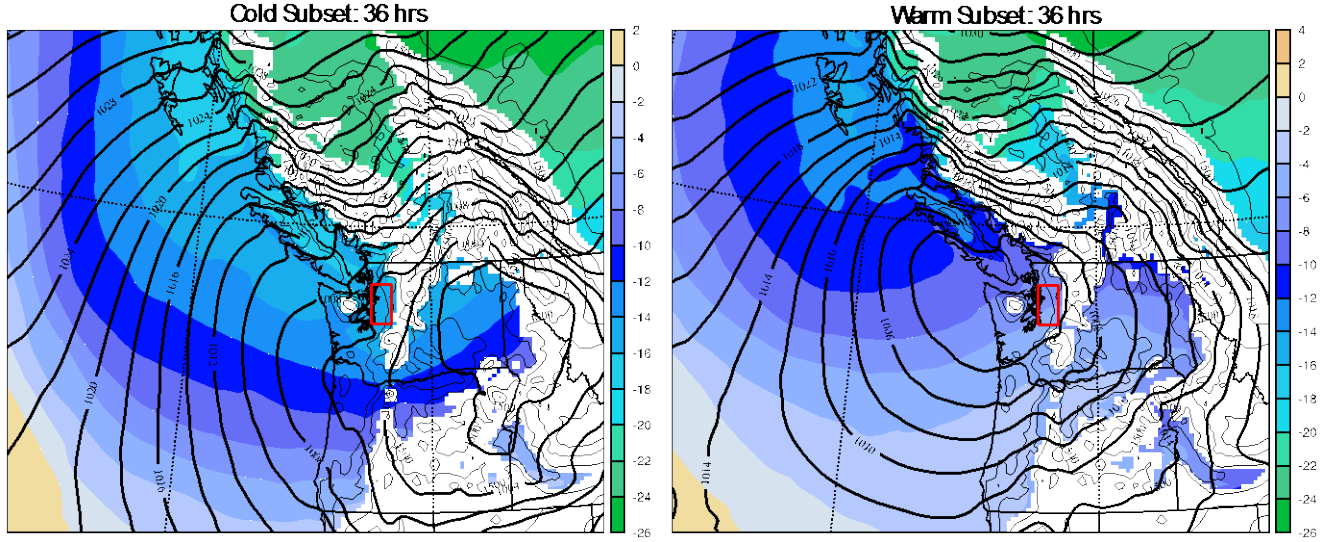


Figure 1: Mean sea-level pressure (black contours) and 850-hPa temperatures (color shading, interval in 2°C steps) for the cold-subset (left) and warm-subset (right) means. The metric box over which the average 850-hPa temperatures are computed to sort the ensemble members is outlined in red.

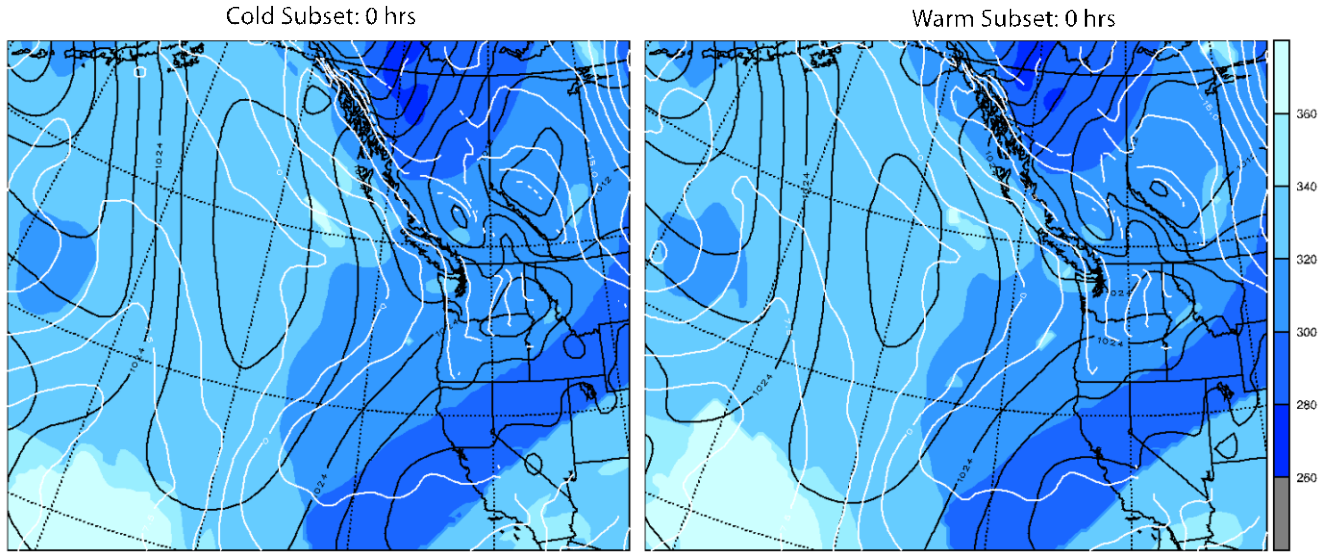


Fig. 2: Each panel shows θ on the 2 PVU surface (color shading), MSLP (black contours), and 850-hPa temperature (white contour). Temperature contours are not plotted where the 850-hPa surface intersects the topography. The region shown is a subset of the full domain.

The limits to predictability in a turbulent fluid with an energy spectrum shallower than k^{-3} (where k is the wavenumber) are classically described as arising from errors in the smallest scales that perturb slightly larger-scale motions, which in turn introduce errors in yet larger scales, thereby leading to an upscale progression of uncertainty. This progression is illustrated in Fig. 3a, which is taken from the idealized model of Rotunno and Snyder (2008), which in turn extends the classic study of Lorenz (1969). Their error-energy spectrum is initially confined to the smallest retained scale, and the upscale evolution is fundamentally different from that for the perturbation kinetic energy (KE') in our 100-member ensemble shown in Fig. 3b. In our simulations, which more accurately describe the atmosphere, the perturbation kinetic energy grows significantly over the first 12 hours at all scales longer than about 100 km. Over the next 12 hours moderate growth occurs at those scales less than 200 km or greater than 700 km. Moderate growth continues at all scales over the final 12-hour period, except there is some suggestion of saturation at wavelengths around 800 km.

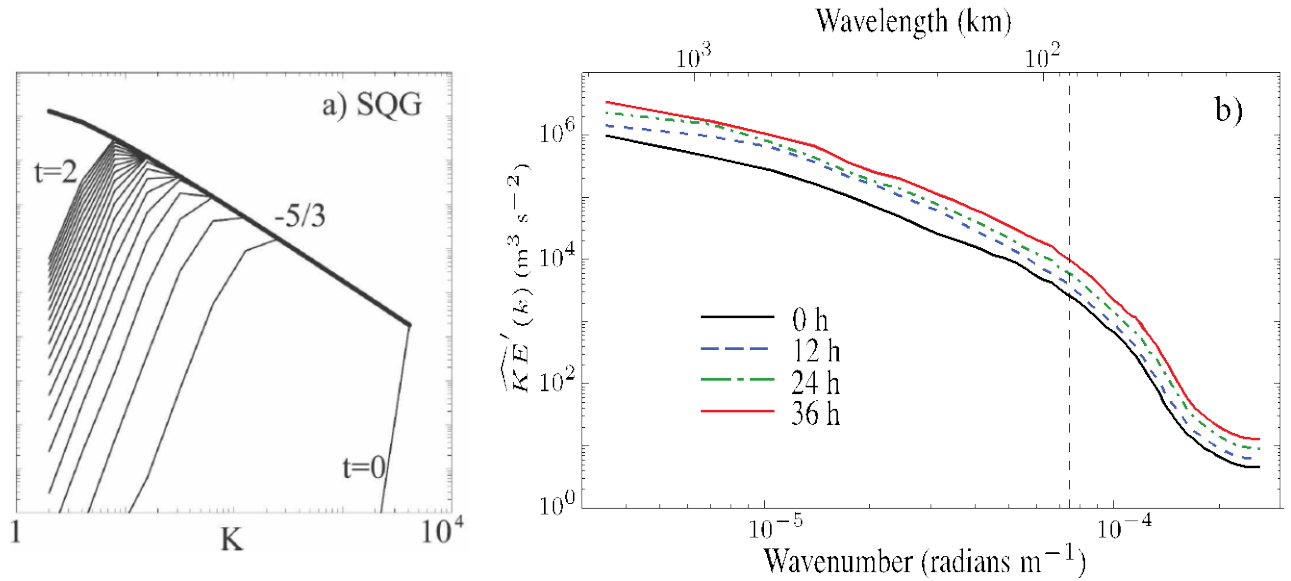


Fig. 3: Evolution of the perturbation kinetic energy spectrum plotted as a function of wavenumber (a) from Rotunno and Snyder (2008) and (b) for the 100-member ensemble forecast of the 17-18 December 2008 snow event. The vertical dotted line highlights the $7\Delta x$ wavelength; waves shorter than the $7\Delta x$ are subject to significant numerical dissipation .

The self-similar shapes of the evolving KE' spectra in Fig. 3b seem to develop because the EnKF data assimilation cycle does not significantly change the shape of the spectrum as it maps the ensemble spread generated by the previous 6-hour forecast (the prior) into the initial ensemble used in the subsequent forecast (the posterior). Turbulence theory suggests that large-scale errors propagate rapidly downscale in fluids with $k^{-5/3}$ energy spectra, such as the atmospheric mesoscale. The presence of such errors in the large scales may, therefore, impose an important previously unrecognized limit on mesoscale predictability.

IMPACT/APPLICATIONS

Forecasting mesoscale meteorological phenomena is of importance to many naval operations, including those in coastal zones, those involving aviation in complex terrain, and those requiring information about the structure of the planetary boundary layer. Understanding the degree of

confidence that can be realistically expected from fine-scale deterministic weather forecasts at various lead times will help meteorologists and other users assess the importance of alternative approaches, such as ensemble forecast systems. The possibility that small initial errors in the large-scale analysis impose a practical limit on mesoscale predictability is a new paradigm that will provide a further impetus wider adoption of the ensemble approach.

RELATED PROJECTS

None

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PUBLICATIONS

- Durrán, D.R., P.A. Reinecke, and J.D. Doyle, 2012: Large-Scale Errors and Mesoscale Predictability in Pacific Northwest Snowstorms. *Mon. Wea. Rev.*, submitted.